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Risk assessment in the Caribbean: modeling a GIS-based Flood risk Tool for Jamaica

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Abstract

The Caribbean is known to be one of the most hazard-prone regions in the world. Although the growing intensity of these disasters increases the concern of decision makers, researchers have not yet succeeded in developing an accurate multi-hazard risk assessment tool to locate the high-risk areas. Many single-hazard risk analyses adequately estimate the risk of one hazard, but the complexity of the relation between the different types of hazards causes difficulties in developing one risk analysis to assess all hazards. This research aims to develop such a model for the Caribbean.

In a first step, a flood risk tool was developed for Jamaica. After optimizing this tool, the methods will be used for other hazard types. In a final step, all single-hazard tools will be combined into one multi-hazard risk assessment. To generate the flood risk tool, a new methodology based on minimizing risks rather than building water defences, was used. In the Flemish Region in Belgium, this method is already used in a tool called LATIS, and has proven that using a risk-based methodology helps tremendously in finding the most cost-efficient measures to reduce risk.

For Jamaica, the lack of data was and is a big concern. Since there was only minimal rainfall data available, flood hazard maps could not be generated. Therefore, a risk map could not yet be computed, only a vulnerability map and a damage map could. Furthermore, the available damage functions did not cover all elements at risk. Before regenerating the damage map, these functions will have to be reassessed. However, the vulnerability map that was produced shows promising results in indicating the high-risk areas, which are the most important factor in the decision making process. Further research will focus on the

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flood hazard maps and the damage functions, before applying this method to other natural hazards.

Keywords: Flood hazard; Vulnerability, Jamaica.

1. Introduction

Between 1975 and 2008, over 2.2 million people worldwide died due to natural hazards (ISDR 2009). With an average annual loss due to hazards that exceeds two percent of the capital stock in 2013, the Caribbean is one of the most hazard-prone regions in the world (UNISDR 2015). The region is characterised by small islands, highly populated coastal areas and climate change impacts. This puts the Caribbean region at great risk for natural hazards, such as earthquakes, volcanic eruptions, tsunamis, landslides, hurricanes and flooding. In the past century, the region was hit at least 18 times by tsunamis alone, resulting in over 2000 deaths (Lander et al. 2002). In Jamaica, the damage of the seven major hazard events that occurred between 2004 and 2010 is estimated at 12 billion USD and 55 fatalities (ODPEM 2012). The expected annual cost of these extensive economic, human and material losses must be budgeted as precise as possible so the governement can take the necesarry measures to protect the country and its inhabitants. However, researching the socially acceptable, manageble and budgetary limits must take priority. In a later stage of the process, an adequate risk assessment that computes and predicts the damage of future hazards is indispensable.

Since climate change and the growing intensity of natural hazards increased the concern among decision makers all over the world, many researchers have focused on risk analysis over the past 20 years. These studies have produced several accurate models that each assess one type of risk. For flooding, for example, many countries have developed their own analysis method. In the Netherlands, HIS (Hoogwater Informatie Systeem) is widely used by regional governements (Rijskwaterstaat 2005) and in Flanders, many decision makers rely on the LATIS flooding tool (Deckers et al. 2010).

In vulnerable regions like the Caribbean, however, natural hazards rarely occur isolated. They often influence other natural hazards. This phenomenon is described as a hazard chain or a cascade (Tarvainen et al. 2006). An example of this phenomenon is an earthquake inducing a landslide. Furthermore, hazard characteristics differ and thus should the methods to analyze them (Carpignano et al. 2009). This makes it difficult to find an overall evaluation methodology. Moreover, the existing approaches are limited in space, as they are specifically designed for a certain area. A multi-hazard analysis is not just the sum of the single-hazard assessments. To date, there is an apparent need for an approach that integrates the complex nature of the hazards and their relation to one another in an adequate manner (Daniell 2011).

To this end, the research at hand aims to develop a generic multi-hazard risk assessment model applicable to the entire Caribbean, but also useful for other vulnerable, developing islands. In a first step, the consequences of each type of natural hazard are assessed. Next, these consequences are categorized and, in a final step, combined into a multi-hazard analysis.

To achieve the first step, a flood risk tool, which will form the basis for the development of a multi-hazard risk assessment, will be computed for Jamaica. This island was chosen as research area because of the existing collaboration with the University of the West Indies, campus Mona. Jamaican decision makers focus on preventing flood by building water defense infrastructures and draining off the river water as quickly as possible. However, shifting from this local approach to a wide catchment approach can minimize the flood risk immensely. This way, defense structures will only be placed where necessary and without harming other regions. This approach that concentrates on minimizing the consequences of flooding can reduce the economic and material losses after a flood event more drastically (Deckers et al. 2010). This risk-based method is already in use in several countries that take on a prominent role in risk analysis, such as the United States, the United Kingdom and the Netherlands. The applied methodology also exists in Flanders, where it is implemented in a GIS-based tool called LATIS. As LATIS has already proven to be a valuable tool for flood risk assessment in Flanders, its principles were used as a starting point for Jamaica.

A town on the north-east coast of Jamaica, Annotto Bay, was selected as case study. This area is characterized by four rivers: the Annotto River, the Pencar River, the Mother Ford Drain and the Crooked River. The highest point is located three meters above Mean Sea Level, which makes Annotto Bay extremely vulnerable to flooding and storm surges. A risk assessment of the area, the Annotto Bay model, was performed in 2012, based on historical data of the flood in 2001 (ODPEM 2012). The output data produced by the tool based on the LATIS principles will be assessed through comparison with this historical data. As a result of this comparison, the method will be refined before applying it on other countries and other natural hazard types.

2. Methods

The implementation of the LATIS methodology on the Caribbean imposes several challenges, with data availability being the most important one. Since the Flemish tool is based on specific regional data, a generalization is necessary to make it applicable for the Caribbean. However, the accuracy of the approach depends to a large extent on the available input data, so generalizations must be implemented without reducing this accuracy. Therefore, the principles of LATIS, as displayed in Fig. 1, are used as the basis for the development of the Jamaican flood risk tool and this scheme was extended with detailed region-specific data. An important consideration in this process is the minimum amount of data needed to create an accurate result. Furthermore, solving the question of how these different types of data can work together in generating an adequate result is one of the main research goals in the future. In the following sub-sections, the data used in this model are discussed and several techniques for efficient and accurate data acquisition are examined.

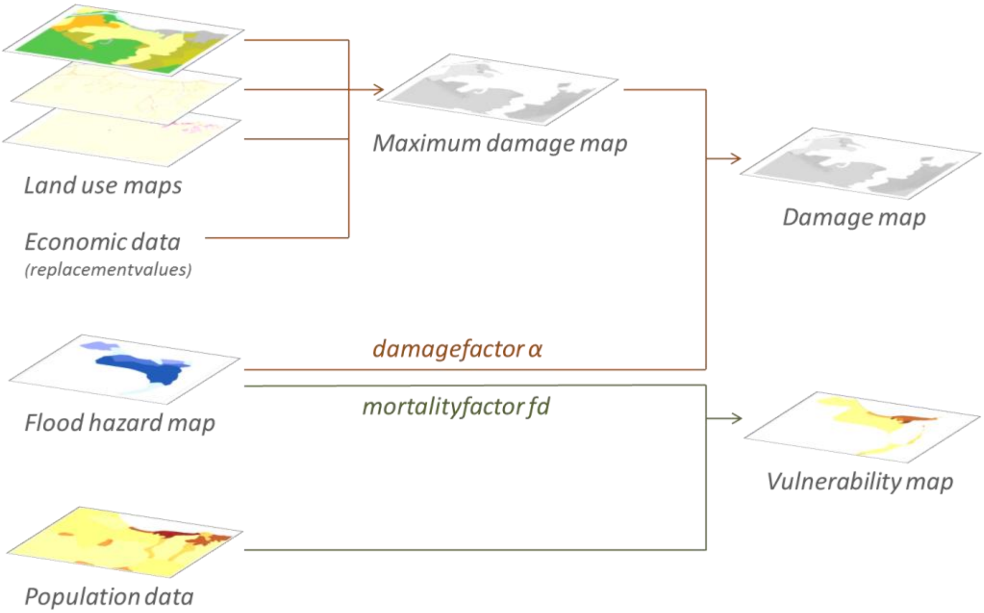

Fig. 1. Risk assessment methodology, based on the LATIS principles.

2.1 Flood hazard map

As the flood hazard map defines the flooded areas and the flood heights, the accuracy of this map largely determines the overall accuracy of the risk assessment. The best results are generated by using realistic hydrological and hydraulic models to develop the flood map. The former can be a rainfall-runoff model that calculates how precipitation reaches the water flow and how fast this river can drain the water. As a result, the hydraulic model produces accurate flood heights and water velocities for a range of scenarios with different probabilities of occurrence, called return periods. To create these models, sufficient rainfall data of the area must be available.

However, this is not the case in Jamaica. The existing rainfall data is very limited in time and space, not only for the study area, but also for the entire island. Therefore, hydrological models can not be generated for the study area. Instead, the existing flood map of one event, the flood of 2001, was used as input in this research. This map gives an accurate overview of the flooded areas and the corresponding water heights, measured during the peak moment of the flood (WRA 2002). Velocities were not incorporated.

2.2 Land use maps, economic data and maximum damage map

Land use maps are a collection of data, defining the physics of the flood area. The level of detail of these maps determines the level of detail of the output. In order to get the best results, the accuracy should be the same for all land use data. That way, no details are lost during the assessment. Following land use data is indispensable for an adequate risk assessment:

- land use map of the study area, with a resolution as high as possible,
- datasets for roads and railroads,

- locations of critical buildings, such as hospitals, fire stations and schools.

This data can be supplemented with information on region-specific infrastructures, crops or buildings to incorporate more detailed data into the assessment. Furthermore, replacement values are added into the analysis. These are estimated as the cost to replace an element at risk, such as buildings, infrastructures or crops, in case of total destruction. The values are derived from land value maps, average crops values or exact replacement values, if this data is available.

For the risk analysis of Annotto Bay, the land use map of the area was used, as well as following data:

- GPS-locations of all buildings in the town, gathered by ODPEM (2012),
- vector data of the roads (ODPEM 2012),
- replacement values of critical buildings, estimated by ODPEM (2012),
- average land cost values for agriculture (FAOSTAT, 2014),
- average building values, estimated by ODPEM (2012).

In a next step, the maximum damage map will be developed by combining the land use maps with the replacement value. This map will show the cost of a total destruction situation for every given type of land use. The maximum damage map will serve as input to create the final damage map.

2.3 Population data

Although this risk assessment focuses on the cost of a possible flood, fatalities are also calculated in the analysis. Therefore, recent population data has to be acquired. To obtain an accurate vulnerability map, the data must be as detailed as possible. For the case study of Annotto Bay, information from 2011 on the number of people in an average household was used. For every statistical district in the town, population data from 2001 is available. By multiplying the number of people per household with the number of houses, accurate and detailed population data per district for 2011 was acquired. This method was statistically tested using the t-test.

2.4 Vulnerability map

The vulnerability of the population is calculated in terms of fatalities per surface area. People who are affected by the flood but survived, are not included in the analysis. Not only the flood height, but also the velocity, which indicates the rate of the water rise, should be taken into account to generate accurate results. Although these velocities were not available, the number of victims can still be calculated with this formula (Vrisou van Eck et al. 2000):

$$fd = \exp(1{,}16 * d - 7{,}3) \tag{1}$$

In formula (1) d is the water height in meter and fd is the mortality factor. In order to map the number of victims, this mortality factor has to be multiplied with the number of inhabitants per surface area, given in square meters. This is done using formula (2):

$$N = fd * A \tag{2}$$

Although these formulae give an estimation of the number of fatalities, there are still a lot of uncertainties, due to a lack of adequate data. These formulae definitely need to be used with caution. The conditions in Jamaica are completely different than the Dutch conditions. Therefore, a reassessment of the formulae is necessary in future research.

2.5 Damage functions and damage map

To generate a damage map as explained in sub-section 2.2, damage functions are indispensable. These are functions that show the percentage of damage to an element at risk in function of the water depth. In previous research, damage factors for different elements such as crops, buildings, roads and furniture have been determined. However, this research focused on flood risk in Europe and the United States. For Jamaica, and other developing countries, no damage functions are available. Therefore, the US damage factors for residential buildings will be used in this risk assessment (Davis & Shaggs 1992). High dummy values will be given to crops, roads and furniture to compensate for the uncertainty.

3. Results

Since this research is still in progress, the results are rather minimal. The first vulnerability map is shown in Fig. 2. To calibrate the results, they will be compared to the historical data of 2001. The damage map has not yet been produced. The values for the crops are being calculated and tested and the available land cost values are being assessed on their accuracy. When all land use data is prepared, the maximum damage map can be generated. With the use of the US damage functions, as mentioned in sub-section 2.5, the Annotto Bay damage map will be produced.

3.1 Vulnerability map

Based on the flood data of the historical flood of 2001 and with the use of the formulae (1) and (2), as mentioned in sub-section 2.4, the vulnerability map for Annotto Bay was generated. Fig. 2 shows the number of fatalities per square kilometer on the level of statistical town districts. The rural areas area characterized by a very low vulnerability, while the low-lying town center has a very high risk of fatalities, up to 8.5 people per km^2.

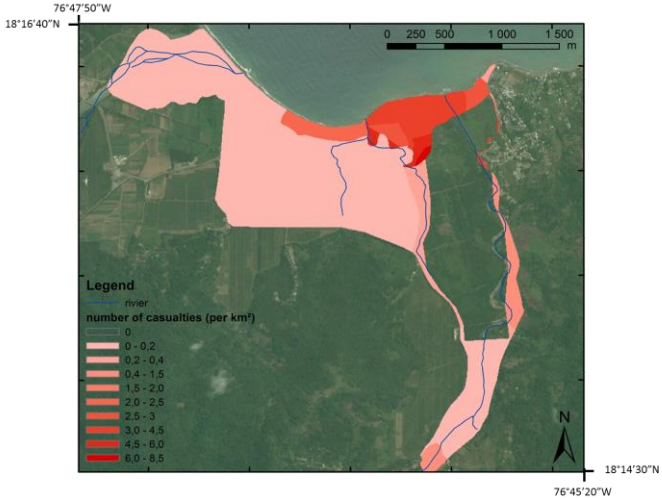

Fig. 2 Vulnerability map of Annotto Bay: number of fatalities

4. Discussion

As shown in section 3, the LATIS risk assessment methodology can be adjusted to fit the research area and the methods can be applied to the Caribbean. Moreover, the first results for the vulnerability map offer a clear view of the areas with a high vulnerability. In a further stage of the research, the output maps will present the regions and infrastructures at risk. This way, the decision makers can optimize their flood protection policy, based on this risk analysis.

In order to produce these adequate output maps, the focus of further research needs to be on obtaining the input data since the lack of flood hazard maps for several return periods hinders the production of risk maps. Based on the data of one flood, the method can only produce damage and vulnerability maps for this one event. In order to predict the material and human losses of future floods, more detailed flood hazard maps are a necessity. Because Jamaica, as well as other Caribbean countries, does not dispose of detailed river information and sufficient rainfall data, hydrological models cannot be drafted. Other methods to calculate return periods and future floods will be examined in the further course of the research, for example the use of satellite imagery. Many studies have proven that remote sensing technology can give a large amount of information in areas where data availability is limited. This is thus definitely a focus in future research.

A second measure to enlarge the accuracy of the risk assessment is the improvement of the damage functions. Therefore, further research will aim on developing damage functions for crops, roads and industry, specific for the Caribbean. Furthermore, the US damage factors for residential buildings, as well as Japanese damage functions, will be tested and evaluated for the houses in the research area.

5. Conclusion

The new risk-based methodology for flood risk assessment in the Caribbean enables a more oriented approach for decision makers. High risk areas can be easily spotted and an estimation of the annual cost of flooding can be produced. This will help the local governments in taking measures to protect their inhabitants and their infrastructures. The first output data of this LATIS-based method shows promising results. Furthermore, in light of the planned improvements, this method will be able to give accurate results and be the guidance in developing risk assessments for different types of natural hazards, affecting the Caribbean.

6. Acknowledgements

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